

COMPARISON OF WALL TEMPERATURES ON SCRAMJET INLETS AT HYPERSONIC VELOCITIES

UJJWAL KANTH¹, C. SATYA SANDEEP², U. SHIVA PRASAD³,
R. SURESH KUMAR⁴ & SIVAKUMAR. E⁵

¹B. Tech Final Year, Department of Aeronautical Engineering, Institute of Aeronautical Engineering, Dundigal, Hyderabad

^{2, 3, 4}Assistant Professor, Department of Aeronautical Engineering, Institute of Aeronautical Engineering, Dundigal, Hyderabad

⁵Assistant Professor, Department of Mechanical Engineering, MLR Institute of Technology, Dundigal, Hyderabad

ABSTRACT

Skin frictions produced at high operational speeds generate lots of heat on the surface of the aircrafts. It is very much essential to determine the quantity of the heat produced on the outermost layer of the vehicle during supersonic flight while choosing the material of vehicle manufacturing. Generation of shock waves at the inlets, makes the case more complicated. This work compares the temperatures generated on the surface of scramjet inlet at Mach numbers 5, 6, 7. The commercial CFD tool is used for the simulation. Spalart- Allmaras turbulence model was used to get proper temperature readings across the entire surface. It was found that at higher Mach numbers, the temperatures generated crossed a thousand degrees giving a definite conclusion that materials with low melting points are not suitable for the design of Scramjets.

KEYWORDS: CFD Analysis, Hypersonic Inlets, Intakes & Scramjet Inlet

Received: Dec 05, 2017; **Accepted:** Dec 26, 2017; **Published:** Jan 12, 2018; **Paper Id.:** IJMPERDFEB2018015

INTRODUCTION

Scramjets are fast moving vehicles capable of propagating at very high Mach numbers. In the year 2002, Queensland University of Australia demonstrated a scramjet engine which successfully moved seven times than the speed of sound. [1] NASA with the U. S Airforce aired the X-51A Wave rider with speed five times the speed of the sound for 200 seconds setting a benchmark. The ability of the scramjet engines to move very fast and reach stipulated distant destinations within less time makes them very popular. Determining the flow parameters and flow behavior experimentally is very costly for supersonic flight. That is why aid of a computer-based simulation is taken into consideration to reduce the experimental cost and visualize the flow. The principle of scramjets is to compress the air before it reaches the combustion chamber, by the generation of shocks by the inlets design. Figure 1 show a typical scramjet inlet design which is taken as a model for simulation in this present work.

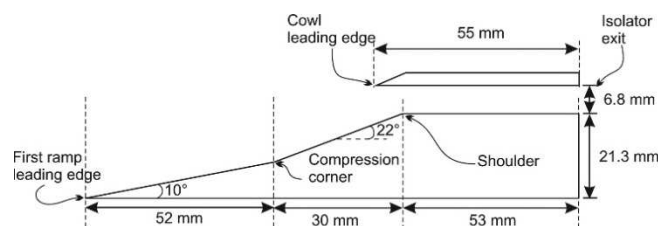


Figure 1: Scramjet Inlet Design

Bo Huang and his team in the year 2009 performed a 3D experimental analysis on scramjet inlet flow, where they concluded that there were three central regions of interaction on the 3-D supersonic inlet. The first shock wave caused by the wedge sidewalls and the boundary layer over the top of the inlet. The second one was shock wave caused by the cowl and the boundary layer over the top and the final shock wave caused by the cowl and the boundary layer over the wedge sidewall. ^[1]In 2014 V. Rajashree and the team performed CFD simulation on hypersonic inlets. They came out to a conclusion that a double ramp inlet comes out with a higher peak pressure than a single ramp inlet. ^[2]Aqeel Murtuza Siddiqui and his team had analyzed scramjet inlet, where they simulated how Mach number is affected by a different number of ramps. ^[3]

PROBLEM DEFINITION AND SIMULATION

A spike inlet with extended lower lip had been designed to simulate at different MACH numbers. The material of the spike has been chosen as titanium, six reference points on the upper and lower spike have been taken where the temperatures at different Mach numbers will be reported. Figure 2 shows the grid generation of the scramjet inlet where temperatures are reported.

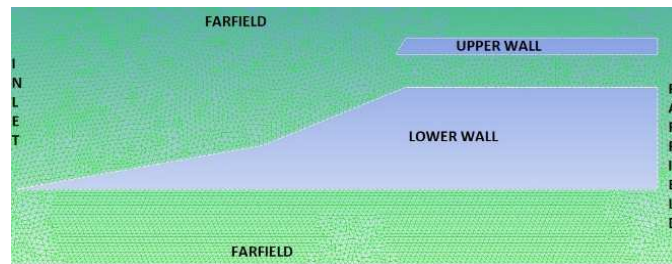


Figure 2: Problem Description

ICEM CFD Module in Ansys was used to generate the grid. The grid was created with 60000 cells 90615 faces and 30500 nodes. The starting of the fluid domain has been taken as velocity inlet where the values of the velocities were varied between Mach 5 to Mach 7. The initial gauge pressure was taken as 2500 Pascal's, and the operation temperature was taken as 200 K. Outlet was taken as pressure outlet with the lower and upper spike named as wall with titanium as its material. Spalart Allmaras turbulence model was used for the simulation while considering the energy equation.

RESULTS AND DISCUSSIONS

The main aim of the simulation was to determine the temperatures generated at the spike wall. Knowing the temperatures on spike wall will enable us to choose an appropriate material to manufacture it. After performing the simulations at different Mach numbers it was observed that formation of shocks near the spike had triggered a large variation in the flow properties. Oblique shock formed as a consequence of the bending of the shock in the free-stream direction. In a supersonic flow through a duct, viscous effects cause the shock to be oblique near the walls, the shock being normal only in the core region. The shock is also oblique when a supersonic flow is made to change direction near a sharp corner. The oblique shock continues to bend in the downstream direction until the Mach number of the velocity component normal to the wave is unity. At that instant, the oblique shock degenerates into a so called Mach wave across which changes in flow properties are infinitesimal.

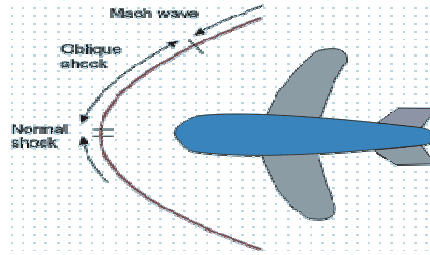


Figure 3: Description of Shock Waves

For analyzing flow through such a shock, it may be considered as a normal shock on which a velocity (parallel to the shock) is superimposed. The change across the shock front is determined in the same way as for the normal shock. The equations for mass, momentum and energy conservation, respectively, are

$$\rho_1 u_1 = \rho_2 u_2$$

$$\rho_1 u_1 (u_1 - u_2) = p_2 - p_1$$

$$h_{01} = h_{02}$$

$$h_1 + \frac{u_1^2}{2} = h_2 + \frac{u_2^2}{2}$$

$$\frac{\gamma}{\gamma-1} \cdot \frac{p_1}{\rho_1} + \frac{u_1^2}{2} = \frac{\gamma}{\gamma-1} \cdot \frac{p_2}{\rho_2} + \frac{u_2^2}{2}$$

$$\frac{u_1}{a_1} = Ma_1 \sin \alpha \quad \text{and} \quad \frac{u_2}{a_2} = Ma_2 \sin \beta$$

Modifying normal shock relations by writing $\sin \alpha$ in place of 1 and $\sin \beta$ in place of 1 , we obtain

$$\frac{p_2}{p_1} = \frac{2\gamma Ma_1^2 \sin^2 \alpha - \gamma + 1}{\gamma + 1}$$

$$\frac{u_2}{u_1} = \frac{\rho_1}{\rho_2} = \frac{\tan \alpha}{\tan \beta} = \frac{\gamma - 1}{\gamma + 1} + \frac{2}{(\gamma + 1) + Ma_1^2 \sin^2 \alpha}$$

$$Ma_2^2 \sin^2 \beta = \frac{2 + (\gamma - 1) Ma_1^2 \sin^2 \alpha}{1 + \tan^2 \alpha (\tan \beta / \tan \alpha)}$$

In order to obtain the angle of deflection of flow passing through an oblique shock, we use the relation

$$\begin{aligned} \tan \theta &= \tan(\alpha - \beta) = \frac{\tan \alpha - \tan \beta}{1 + \tan \alpha \cdot \tan \beta} \\ &= \frac{\tan \alpha - (\tan \beta / \tan \alpha) \tan \alpha}{1 + \tan^2 \alpha (\tan \beta / \tan \alpha)} \end{aligned}$$

$$\tan \theta = \frac{Ma_1^2 \sin 2\alpha - 2 \cot \alpha}{Ma_1^2 (\gamma + \cos 2\alpha) + 2}$$

The following relationship for the Mach numbers upstream and downstream of a normal shock wave

$$\frac{Ma_1}{1 + \gamma Ma_1^2} \left[1 + \frac{\gamma - 1}{2} Ma_1^2 \right]^{\frac{1}{2}} = \frac{Ma_2}{1 + \gamma Ma_2^2} \left[1 + \frac{\gamma - 1}{2} Ma_2^2 \right]^{\frac{1}{2}}$$

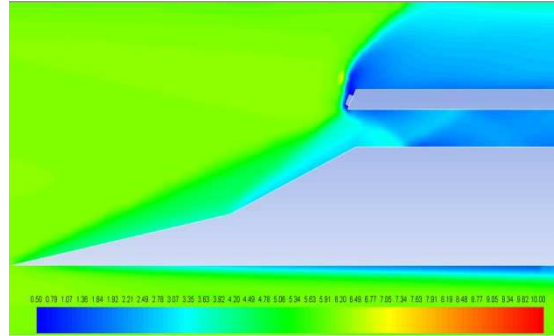


Figure 4: MACH Contours at M=5

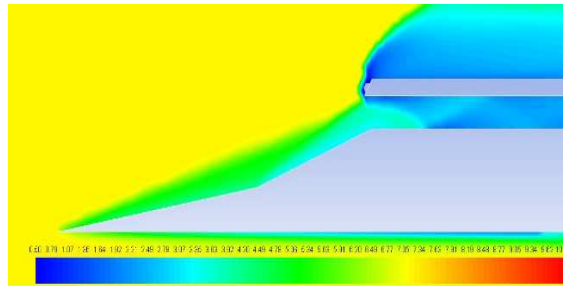


Figure 5: MACH Contours at M=6

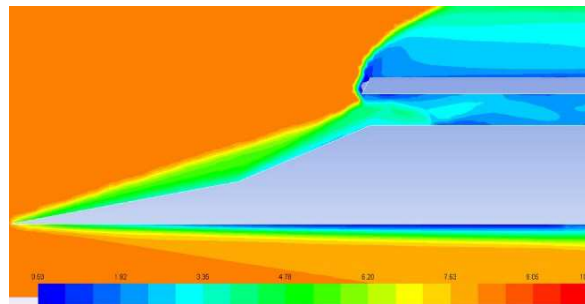


Figure 6: MACH Contours at M=7

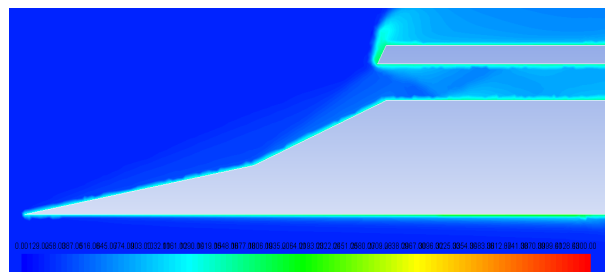


Figure 7: Static Temperature Contours at M=5 (Range Min 0 K and Max 4300 K)

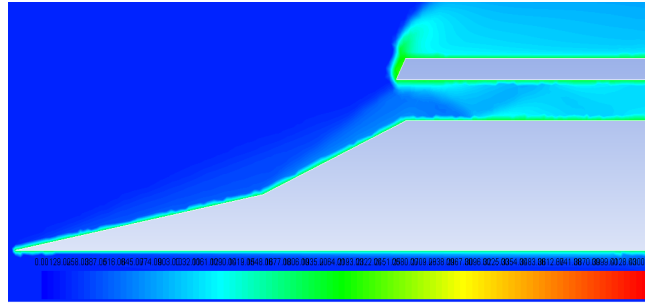


Figure 8: Static Temperature Contours at M=6 (Range Min 0 K and Max 4300 K)

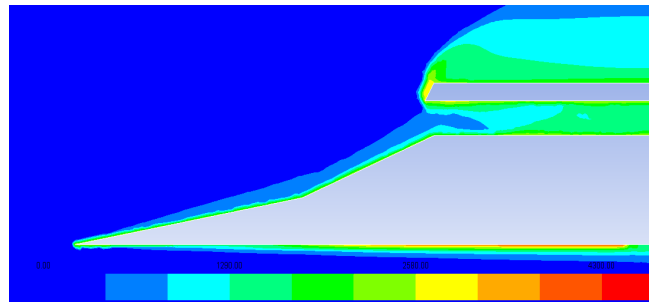


Figure 9: Static Temperature Contours at M=7 (Range Min 0 K and Max 4300 K)

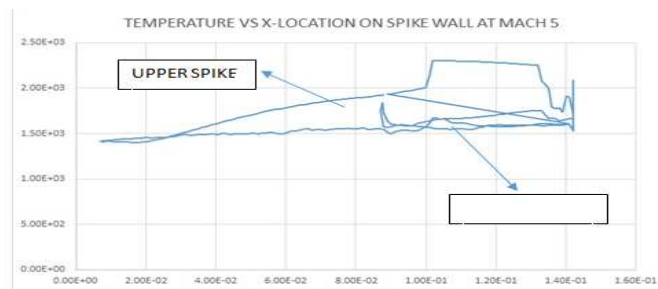


Figure 10: Temperature Variation on Spike along X-Axis at MACH 5

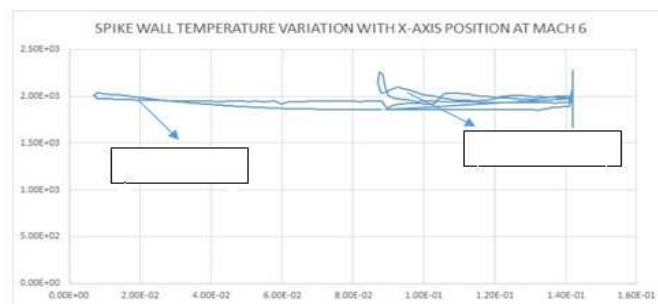


Figure 11: Temperature Variation on Spike along X-Axis at MACH 6

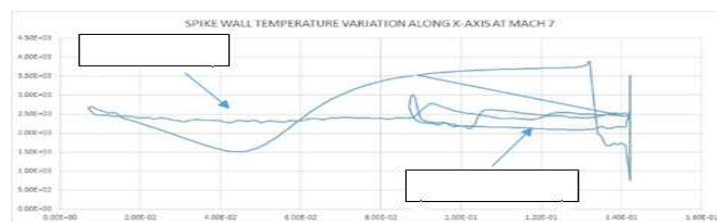


Figure 12: Temperature Variation on Spike along X-Axis at MACH 7

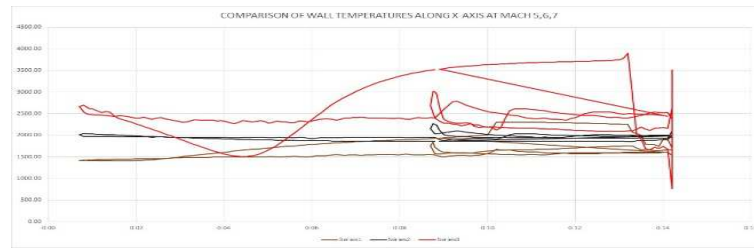


Figure 13: Comparison of Wall Temperatures at Mach 5, 6, 7 (Blue, Black Red Respectively)

CONCLUSIONS

Comparison of the temperatures generated on the surface of scramjet inlet at Mach numbers 5, 6, 7 using Spalart-Allmaras turbulence model was performed to get proper temperature readings across the entire surface. The flow across the inlet at Mach 5, 6, 7 could be clearly seen in figures 4, 5 and 6. The temperature variation was shown in figures 7, 8 and 9. Figures 10,11,12 show the plots of the temperature variation along the spike wall and figure 13 compares the same for all the three different Mach numbers. With the help of the computational simulation, the high temperatures on the wall of the scramjet inlet have been identified and are tabulated in Table 1.

Table 1: Maximum Recorded Temperatures on Scram Jet Wall

S. NO	MACH NUMBER	MAXIMUM RECORDED WALL TEMPERATURE IN KELVIN
1	5	2086
2	6	2274
3	7	3902

A study of the temperatures generated will enable us to select a suitable material to manufacture the spike which can possibly withstand those high temperatures.

REFERENCES

1. Bo Huang, Zhufei Li, Jiming Yang, Xisheng Luo, "An experimental observation of 3-d scramjet inlet flow in shock tunnel", 10th International conference on fluid control, Measurements and visualization, August 2009, Moscow, Russia.
2. V. Rajashree, P. Mani vannan, G. Dinesh Kumar, "Computational Analysis of Scramjet Inlet," International Journal of Innovative Research in Science, Engineering, and Technology, Volume 3, Special Issue 3, March 2014.
3. Gangaraju Srinivasa Sharma, M. V. S. Murali Krishna & D. N. Reddy, CFD Analysis for Adaptability of Producer Gas for Power Generation in Gas Turbines, International Journal of Mechanical and Production Engineering Research and Development (IJMPERD), Volume 5, Issue 2, March - April 2015, pp. 21-32
4. Aqeel Murtuza Siddiqui, G. M. Sayeed Ahmed, "Design and Analysis on Scramjet Engine Inlet," International Journal of Scientific and Research Publications, Volume 3, Issue 1, January 2013.
5. Rajesh V. Raut & Kiran M. Chaudhari, CFD Analysis of Solar Heater Water Pipe with Different Inclination International Journal of Mechanical and Production Engineering Research and Development (IJMPERD), Volume 4, Issue 2, March - April 2014, pp. 55-62
6. https://www.nasa.gov/missions/research/f_scramjets.html.
7. http://www.nptel.ac.in/courses/112104118/lecture-41/41_6_oblique_shock.htm.